Rotary Screw Compression Process

Prepared for the Gas Machinery Research Council Conference
October 7, 2003
Salt Lake City, Utah

Prepared by: Jeffrey R. LaPlante
Ariel Corporation

I. Introduction:

As the reservoir pressure of major gas producing fields continues to decline, additional compression is required to maintain production rates and produce the reserves associated with lower abandonment pressures. The rotary screw compressor, due to its small size, lower capital cost, and reasonable efficiency at lower operating pressures, is well suited for natural gas gathering operations. As more gas producing fields mature and gathering system pressures decline, the rotary screw compressor will likely be applied more frequently.

This paper will discuss the following aspects of rotary screw compression:

- The rotary screw compression process
- Rotary screw volume ratio
- Rotary screw capacity control
- Rotary screw lubrication systems

II. Rotary Screw Compression Process:

A rotary screw compressor is a positive displacement device. Like a reciprocating compressor, the gas pressure is increased due to a reduction in volume, following the real gas laws. However, the process by which the volume is reduced in a rotary screw compressor is significantly different than the volume reduction process in a reciprocating compressor.

The compression process in a rotary screw compressor occurs in three dimensions. Therefore, it is often difficult to show the process using two-dimensional drawings. As a result, a 15 minute "Rotary Screw Compression Theory" video has been produced, and will be shown in addition to this discussion. If additional videos are required, please contact Ariel Corporation.

Figure 1 below shows common rotor terminology. The flutes are the open areas between lobes that fill with gas. A reciprocating compressor equivalent would be a cylinder. The lobes separate the different flute spaces, and then also mesh with the flute spaces to reduce flute volume and compress the gas. In reciprocating compressor terms, the lobes are pistons.

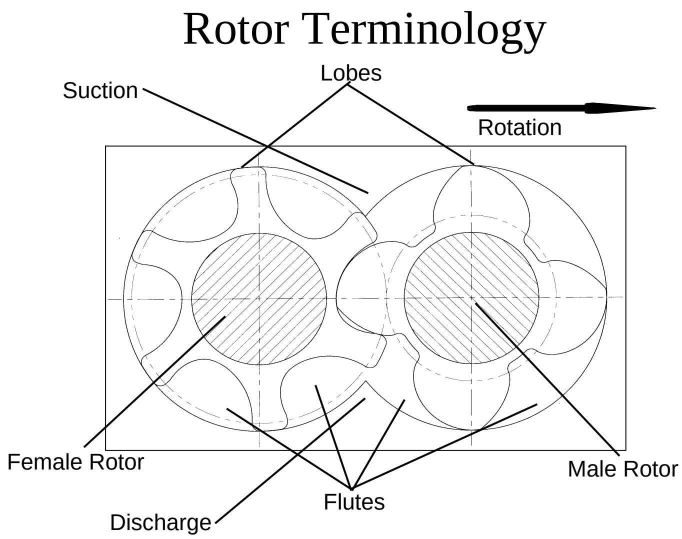

Figure 1: Common rotor terminology

The Pressure-Volume card, shown in Figure 2, can be used to explain the compression process in rotary screw compressors. At the beginning of the compression cycle, gas at suction pressure fills the flute spaces as the rotors unmesh under the suction flange. Gas continues to fill the flute spaces, until the trailing lobe crosses the inlet port. At that point, the gas is trapped inside the flute space. This is defined as the inlet volume, in acutal volume terms.

On the underside of the rotary screw compressor, the rotors begin to mesh. As the lobe meshes into the flute space, the flute volume is reduced, causing the pressure to increase. The volume reduction and subsequent pressure increase will continue as long as the gas is trapped in the flute space.

Gas is discharged from the flute space when the leading lobe crosses the discharge port. The actual volume at this point in the compression cycle is defined as the discharge volume.

There is a volume of gas remaining in the flute space after the leading lobe crosses the discharge port. Further rotation and meshing of the rotors forces this gas from the flute space into the discharge line. However, there is no additional pressure increase as a result of this volume reduction, since the flute space is no longer sealed.

A rotary screw compressor has no clearance, so there is no clearance expansion at the end of the discharge event. Theoretically, a rotary screw compressor would have 100% volumetric efficiency, but there is not a gas-tight seal between the rotors and between the rotors and the housing. This causes leakage between flutes and lowers the volumetric efficiency. Leakage is a function of compressor tip speed and pressure difference, and will decrease the inlet volume to about 90% of displacement.

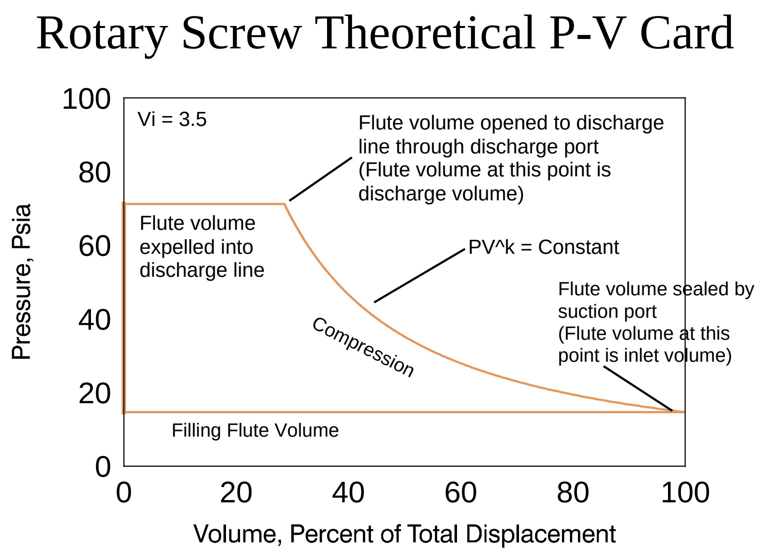

Figure 2: Theoretical P-V card for rotary screw compressors

III. Volume Ratio:

The volume ratio of a rotary screw compressor is defined by the equation below:

$$V_i = \frac{\text{Inlet volume, acf}}{\text{Discharge volume, acf}}$$

The volume ratio is related to the internal pressure ratio that is developed inside the flute spaces due to volume reduction.

$$P_i = V_i^k$$

A compressor with a fixed volume ratio will develop the same internal pressure ratio, regardless of line pressure. Many compressors that have an axial port only have a fixed volume ratio. Other compressors have changeable volume ratio, by removing a slide valve (that contains a radial discharge port), and replacing it with a slide valve that has a different sized radial port. Others can vary the volume ratio while the compressor is in operation. Volume ratio is changed by changing the size or location of the discharge port. A smaller discharge port will increase the volume ratio by holding the gas inside the flute space longer than a larger discharge port. The longer the gas is held inside the flute space before it is allowed to communicate with the discharge line, more rotation, volume reduction, and subsequent pressure increase occurs. Figure 3 shows an axial port and different volume ratio radial ports.

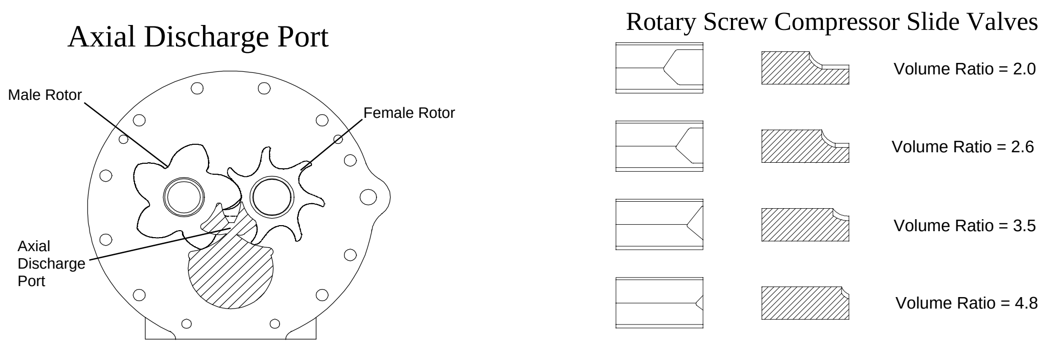

Figure 3: Axial and radial discharge ports for rotary screw compressors

For best efficiency, the volume ratio should be sized so than the internal compression ratio matches the system compression ratio. If the internal compression ratio does not match the system compression ratio, the result is either overcompression, or undercompression. See Figure 4, an Over/under compression P-V card.

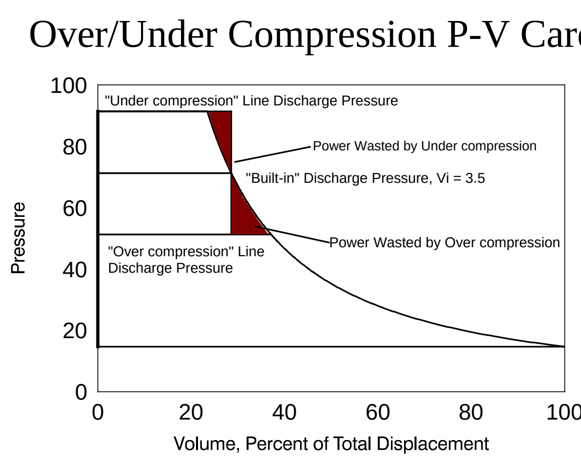

Figure 4: Over/under compression P-V card:

In overcompression, the gas is compressed more than the system requires. Gas is compressed to the internal discharge pressure, and then expands down to suction pressure. Extra work is required to compress the gas to the internal discharge pressure, rather than to the system discharge pressure.

With undercompression, the gas is internal discharge pressure is lower than the system discharge pressure. Gas from the discharge line backflows into the flute space, equalizes pressure, and must be compressed again. Extra work is required to compress the same gas twice.

Generally, overcompression is less efficient than undercompression. In overcompression, extra work is done on all the entire flow stream, while in undercompression, extra work is done only on the gas that backflows into the flute space from the discharge line.

IV. Capacity Control:

Since a rotary screw compressor is a postive displacement device, the capacity control methods are similar to other positive displacement devices, namely reciprocating compressors. Capacity control methods, in order of decreasing efficiency, are as follows:

- Rotating speed
- Internal bypass
- Suction throttling
- Unit bypass

Of these capacity control methods, the only one that is affected by the internals of the compressor is internal bypass. Internal bypass can be operated with poppett valves, by opening bypass slots in the rotor housing, or by moving a slide valve towards the discharge end of the compressor (Figure 5).

Opening the internal bypass changes the location of the suction port, effectively shortening the length of the rotors. Shortening the effective length of the rotors reduces the capacity, as the sealing point takes place after the rotors begin to mesh and reduce flute volume. Gas is pushed back into the suction area with rotor meshing until the trailing lobe crosses the sealing point.

As a consequence of reducing inlet volume, the volume ratio is also affected. Even compressors with variable volume ratio lose volume ratio control once capacity reduction occurs. Since the inlet volume and discharge volume are both a function of slide valve position, they cannot be controlled independently. Two devices, one to control inlet volume, and another to control discharge volume would be required to control volume ratio with capacity reduced using internal bypass. Figure 6 shows a characterist Vi vs. slide valve axial position curve for a slide valve compressor.

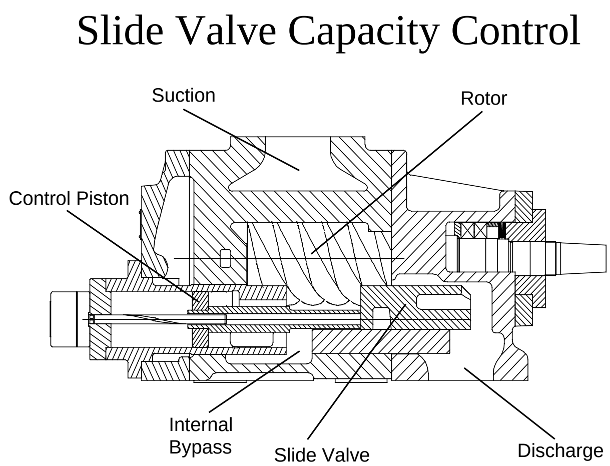

Figure 5: Slide valve capacity control

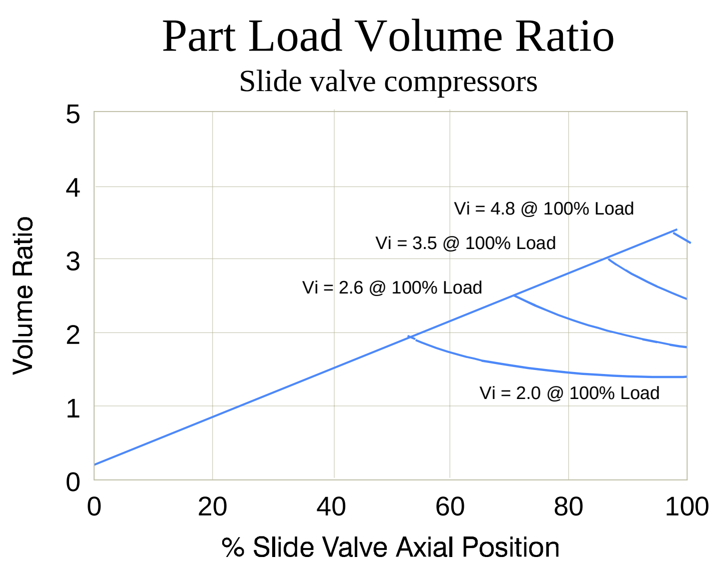

Figure 6: Volume ratio vs. slide valve axial position

V. Oil System:

Oil flooded rotary screw compressors have oil injected directly into the compression chamber, in addition to oil used for lubricating the bearings and mechanical seal. Oil can also be used to actuate hydraulic capacity controls.

Oil lubricates, seals, and absorbs the heat of compression in oil flooded rotary screw compressors. This allows for better efficiency and higher allowable compression ratios compared to oil free rotary screw compressors. However, the oil comes into contact with the process gasses, which can make oil selection an issue, and also gas/separation on the discharge of the compressor is required.

A typical oil system schematic is shown as Figure 7.

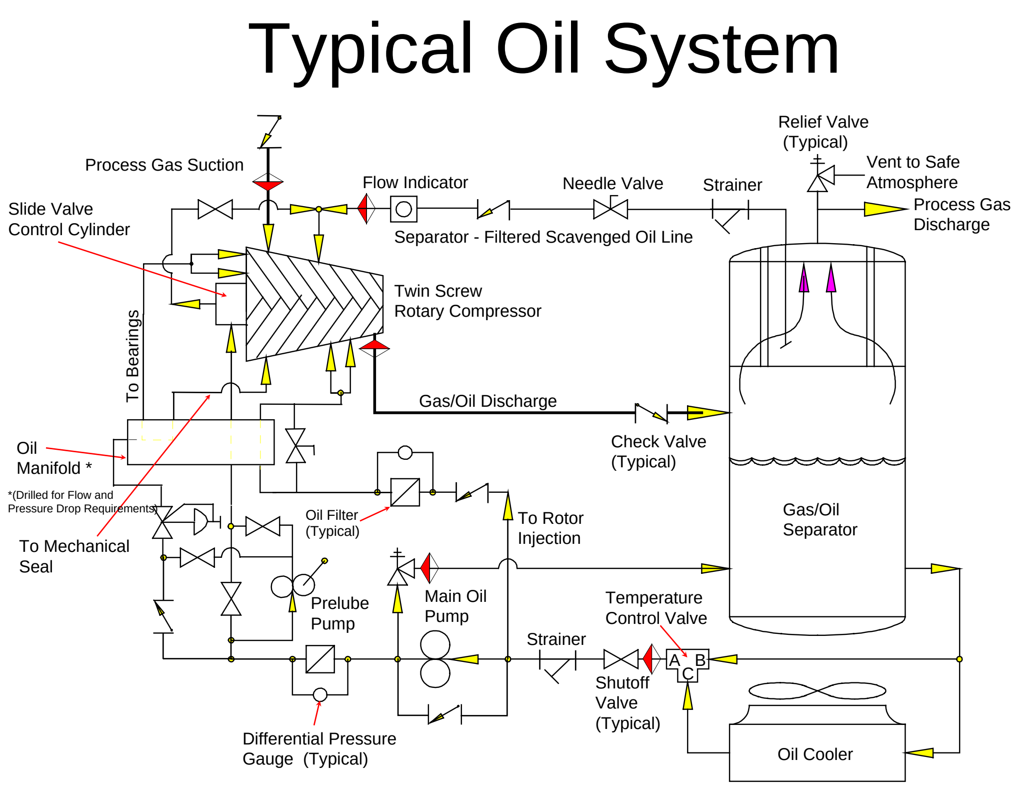

Figure 7: Oil system schematic

VI. Summary:

- Rotary screw compressors are positive displacement compressors.

- Rotary screw compressors have no valves, and therefore rely on porting to determine when the gas is sealed for compression to begin, and released to the discharge line.

- Internal compression ratio can be changed by changing the location of the discharge port.

- Capacity can be changed by changing the point at which the flute spaces are sealed for compression to begin.

- Volume ratio and capacity cannot be independently controlled unless there are two control devices, one to independently contol inlet volume, one to independently control discharge volume.

- Oil is used to lubricate, seal and absorb the heat of compression. Challenges with oil selection and gas/oil separation are overcomable in most cases.